Quality in Sport. 2026;52:68991. eISSN 2450-3118.

https://doi.org/10.12775/QS.2026.52.68991

Quality in Sport. eISSN 2450-3118

Journal Home Page
https://apcz.umk.pl/QS/index

MODELSKA, Julia, JELEŃ, Anita, PODOLSKA, Anna, PALUCHOWICZ, Karolina, SIWICKA, Katarzyna, SZEWCZYK, Konrad, JANASIK, Laura, KOCIUCKA, Patrycja and SADOWSKI, Krzysztof. Epidemiology, mechanisms and prevention of electric scooter-related injuries with particular emphasis on the pediatric population - a narrative literature review. Quality in Sport. 2026;52:68991. eISSN 2450-3118. https://doi.org/10.12775/QS.2026.52.68991

The journal has been awarded 20 points in the parametric evaluation by the Ministry of Higher Education and Science of Poland. This is according to the Annex to the announcement of the Minister of Higher Education and Science dated 05.01.2024, No. 32553. The journal has a Unique Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).
The authors declare that there is no conflict of interest regarding the publication of this paper.
Received: 15.02.2026. Revised: 19.02.2026. Accepted: 19.02.2026. Published: 28.02.2026.

Title: Epidemiology, mechanisms and prevention of electric scooter-related injuries with particular emphasis on the pediatric population - a narrative literature review

Authors:

1. Julia Modelska[1]

https://orcid.org/0009-0009-3972-9126

jula.modelska@gmail.com

[1] Prof. S. T. Dąbrowski Hospital in Puszczykowo S.A.,

11 Józefa Ignacego Kraszewskiego Street, 62-040 Puszczykowo, Poland

2. Anita Jeleń[2]
https://orcid.org/0000-0001-6274-0969
anita.jelen1@gmail.com
[2] University Clinical Hospital in Poznań,
49 Przybyszewskiego Street, 60-355 Poznań, Poland

3. Anna Podolska[3]
https://orcid.org/0000-0002-1365-341X
annapodolska13@gmail.com
[3] University Clinical Hospital no. 2 of the Pomeranian Medical University in Szczecin
Powstańców Wielkopolskich 72 Street, 70-111 Szczecin, Poland

4. Karolina Paluchowicz[2]
https://orcid.org/0009-0004-0391-5756
karolina.paluchowicz@gmail.com
[2]University Clinical Hospital in Poznań,
49 Przybyszewskiego Street, 60-355 Poznań, Poland

5. Katarzyna Siwicka[4]
https://orcid.org/0009-0004-9217-5760
kasiasiw2000@gmail.com
[4] PCK Marine Hospital in Gdynia
Powstania Styczniowego 1, 81-519 Gdynia, Poland

6. Konrad Szewczyk[5]
https://orcid.org/0009-0007-9182-9875
konradszewczyk27@gmail.com
[5] Pomeranian Medical Univeristy in Szczecin
Rybacka 1, 70-204 Szczecin, Poland

7. Laura Janasik[6]
https://orcid.org/0009-0003-8384-4793
laura.janasik@gmail.com
[6] Józef Struś Memorial Multidisciplinary Municipal Hospital,
Szwajcarska 3 Street, 61-285 Poznań, Poland

8. Patrycja Kociucka[2]
https://orcid.org/0009-0003-9053-1496
patrycja.kociucka@gmail.com
[2] University Clinical Hospital in Poznań,
49 Przybyszewskiego Street, 60-355 Poznań, Poland

9. Krzysztof Sadowski[1]
https://orcid.org/0009-0001-2344-446X
sadowski.lek@gmail.com
[1] Prof. S. T. Dąbrowski Hospital in Puszczykowo S.A.,
11 Józefa Ignacego Kraszewskiego Street, 62-040 Puszczykowo, Poland

Corresponding author: Julia Modelska, jula.modelska@gmail.com

Abstract

Background: Over the past decade, electric scooters have become a common element of urban micromobility, offering a convenient and environmentally friendly alternative to short-distance car travel. However, the rapid growth in the number of users has not been supported by parallel infrastructure development or consistent legal regulations, leading to a growing number of injuries related to their use. These incidents place a growing burden on healthcare systems, particularly emergency departments and trauma surgery.

Aim: The aim of the study was to review the current literature on epidemiology, accident mechanisms, types and locations of injuries, and strategies for preventing injuries related to the use of electric scooters, with particular emphasis on the pediatric population.

Materials and methods: A narrative literature review was conducted using the PubMed and Scopus databases. Studies on e-scooter-related injuries were analyzed, including epidemiological data, injury mechanisms, risk factors, anatomical injuries, and preventive measures.

Results: Available research indicates a rapid increase in the number of injuries associated with e-scooter use in various regions of the world. Young adults are the most injured group, but children and adolescents are at increased risk of serious injury. The predominant mechanism of injury is falls without the involvement of other road users. The most common injuries are head and facial injuries, as well as upper limb fractures. Failure to wear a helmet, driving under the influence of alcohol, driving at night, and excessive speed are the main risk factors.

Conclusions: Injuries related to e-scooter use constitute a significant and growing public health challenge. Effective prevention requires comprehensive measures encompassing legal regulations, user education, infrastructure improvements, and the implementation of technological solutions.

Key words: electric scooters; micromobility; injuries; trauma; injury prevention; public health

1. Introduction

Over the past decade, electric scooters have become an integral element of so-called urban micromobility, dynamically changing the transport landscape in urban areas. Their widespread availability, relatively low operating costs, ease of use, and perceived beneficial environmental impact have made them highly popular as an alternative to car transport, especially over short distances. The development of shared scooter systems has contributed to a rapid increase in the number of users, but this process has not been supported by adequate road infrastructure

development or clear and consistent legal regulations, which has consequently led to an increase in the number of traumatic incidents [1].

From a public health perspective, injuries related to the use of electric scooters constitute a significant and growing epidemiological problem. Studies conducted in various countries indicate a significant increase in the number of emergency room visits and hospitalizations related to injuries sustained while riding electric scooters. These injuries encompass a wide spectrum of injuries, from soft tissue injuries and limb fractures to severe craniocerebral trauma and multiple organ injuries requiring surgical treatment and long-term rehabilitation [1,2].

The health consequences of these injuries extend beyond the acute phase of treatment, often leading to chronic pain, limited functional capacity, and a reduced quality of life for patients. At the same time, there is a growing burden on healthcare systems, including emergency departments, trauma and orthopedic departments, and surgical units, generating significant direct and indirect costs. Therefore, understanding the scale of the problem, the epidemiological characteristics of injuries, the mechanisms of their development, and identifying key risk factors are fundamental to developing effective preventive strategies and shaping health and transportation policies [2].

2. Methods

This paper is a narrative literature review. Research articles available in the PubMed and Scopus databases were analysed. Observational studies, analyses of trauma registries, systematic reviews, and meta-analyses were included. The search was conducted using a combination of keywords and Boolean operators, including: *"electric scooter"*, *"e-scooter"*, *"electric scooter injury"*, *"e-scooter injuries"*, *"micro-mobility injuries"*, *"head injury"*, *"facial trauma"*, *"fracture"*, *"alcohol"*, *"helmet use"*, *"pediatric"* and *"injury prevention"*. The search and analysis of the available scientific literature were performed independently by each author. Studies languages other than English were excluded. No time criterion was used.

3. Epidemiology of electric scooter-related injuries

Available epidemiological data clearly indicate a dynamic and significant increase in the number of injuries associated with the use of e-scooters, observed in recent years in parallel with the widespread adoption of shared scooter systems. Population studies and analyses of emergency department data conducted in the United States, European countries, and Australia

show a several-fold increase in the number of hospital emergency department visits in the relatively short time since these vehicles were introduced into everyday urban use, clearly indicating a growing public health problem [3-5]. Demographic analyses show that the most frequently injured group is young adults, primarily those aged 20–40, which is directly consistent with the structure of e-scooter users in the general population. This age group is both most exposed to micromobility vehicles and more likely to engage in risky behaviours, which may partially explain the increased incidence of injuries [1,6]. Electric scooter-related injuries occur primarily in urban environments, most often on roads and sidewalks, where interactions with other road users or loss of stability on uneven surfaces occur. Numerous studies indicate that the incidence of traumatic events significantly increases during evenings, nights, and weekends, which may be related to the recreational nature of scooter use, increased pedestrian traffic, and increased alcohol consumption during these periods [7,8]. Comparisons between different regions and countries also suggest that the observed differences in the frequency and severity of injuries may result from different legal regulations regarding the use of electric scooters, the level of enforcement of existing regulations, as well as the availability and quality of infrastructure dedicated to micromobility, such as dedicated lanes or appropriate signage [9,10].

4. Accident mechanisms

The most common injury mechanism associated with electric scooter use is a fall without the involvement of other road users. Such incidents typically occur because of loss of balance, sudden braking, improper vehicle maneuvering, or due to uneven surfaces such as curbs, potholes, or urban infrastructure. The design of electric scooters, characterized by small wheels and a high center of gravity, contributes to vehicle destabilization even over minor obstacles, significantly increasing the risk of a sudden fall, especially at higher speeds [7]. More serious injuries occur in collision-type accidents. Collisions with motor vehicles, cyclists, or pedestrians, while less common than isolated falls, are associated with higher trauma energy and more often lead to multiple organ injuries, head injuries, and hospitalization. Such incidents occur primarily in urban environments, where electric scooters operate in shared spaces with other road users, often without clearly separated infrastructure. Accidents caused by technical failures of scooters, such as braking failure, sudden wheel lockup, or steering mechanism damage, are also described in the literature, but these constitute a significant minority of

reported incidents [4]. Behavioural factors related to the user play a significant role in the pathogenesis of injuries. Driving under the influence of alcohol is one of the strongest risk factors, both in terms of accident frequency and injury severity. Alcohol impairs motor coordination, reaction time, and road situation assessment, which, combined with the scooter's unstable design, significantly increases the risk of falls or collisions. Equally important is the lack of protective helmet use, which remains common among scooter users and correlates with a higher incidence of head and facial injuries. Additional risk factors include excessive speed and cell phone use while riding, which leads to distraction and delayed reactions to hazards [1]. Epidemiological studies also indicate a significantly increased risk of accidents at night. This phenomenon is associated with limited visibility, inadequate lighting on scooters and road infrastructure, as well as increased alcohol consumption in the evening and at night. Consequently, nocturnal trauma events are more likely to have a more severe clinical course and a higher rate of hospitalization [11].

5. Types and location of injuries.

The spectrum of injuries reported among e-scooter users is dominated by craniofacial trauma, fractures of the upper extremities and soft tissue lesions, including contusions, abrasions, and lacerations. This characteristic anatomical distribution reflects the typical injury mechanism associated with e-scooter incidents, namely a sudden fall from a relatively low height combined with considerable forward velocity. The absence of structural protection, limited vehicle stability, and small wheel diameter predispose riders to abrupt loss of balance, resulting in direct impact to exposed body regions. Evidence derived from emergency department records and population-based studies consistently indicates that these injury categories constitute majority of reported cases and are responsible for a substantial proportion of hospital admissions and utilization of acute care resources [3,12].

Head injuries represent one of the most clinically significant consequences of e-scooter-related trauma. The spectrum of cranial and intracranial lesions ranges from mild traumatic brain injury, including concussion, to complex skull fractures and intracranial hematomas necessitating urgent neurosurgical intervention. Epidural and subdural hematomas, cerebral contusions, and diffuse axonal injury may lead to acute neurological deterioration and require intensive monitoring, advanced neuroimaging, and operative management. A particularly important and modifiable risk factor for severe craniocerebral trauma is the absence of protective helmet use,

which remains highly prevalent among e-scooter riders. Multiple studies have demonstrated a statistically significant association between lack of head protection and both increased incidence and greater severity of neurological injury, as reflected by lower Glasgow Coma Scale scores, higher rates of surgical intervention, and prolonged hospitalization [6].

Upper limb fractures constitute another predominant injury category. These fractures most commonly involve the distal radius and ulna and result from an instinctive defensive response during a fall, in which the rider extends the upper extremities to attenuate the impact. This biomechanical mechanism facilitates transmission of kinetic energy through the wrist and forearm to the elbow joint, predisposing to a range of fracture patterns, including simple transverse fractures, intra-articular fractures, and comminuted lesions. Such injuries frequently require operative fixation, particularly in cases with displacement, joint involvement, or instability, and may be associated with long-term functional impairment if not adequately managed [13].

Injuries affecting the thorax, abdomen, and lower extremities are observed less frequently in comparison to craniofacial and upper limb trauma; however, in the context of high-energy mechanisms, such as collisions with motor vehicles or high-speed impacts, they may present as severe, multi-system injuries. These can include rib fractures with associated pulmonary contusion, intra-abdominal organ injury, femoral fractures, and complex soft tissue damage, necessitating multidisciplinary management and, in some cases, admission to intensive care units. Available clinical analyses underscore that a considerable proportion of individuals injured in electric scooter accidents require inpatient treatment, and a significant percentage undergo surgical procedures, particularly in cases involving comminuted fractures, craniofacial trauma, and neurological complications [10].

6. Pediatric population

Children and adolescents constitute a particularly vulnerable subgroup of e-scooter users, owing to developmental immaturity in executive functioning, limited capacity for anticipatory risk assessment, and insufficient experience in road traffic environments. Neurodevelopmental factors, including incomplete maturation of the prefrontal cortex, contribute to impulsivity and suboptimal hazard perception, which in turn translate into a higher propensity for unsafe riding behaviors. Data derived from emergency department registries consistently demonstrate that this population exhibits a disproportionate burden of traumatic injuries. The most frequently

reported lesions include traumatic brain injuries such as concussions, intracranial hematomas, and skull fractures, as well as fractures of the upper extremities, particularly involving the distal radius and ulna. These skeletal injuries are typically the consequence of reflexive protective mechanisms, whereby children instinctively extend their upper limbs to attenuate the impact of a fall. Compared to adults, pediatric users demonstrate significantly lower adherence to recommended protective measures, including the use of certified helmets and limb protectors, which substantially amplifies both the severity of trauma and the risk of acute and long-term neurological as well as surgical complications [14,15]. Limited risk assessment skills and lack of road experience increase children's susceptibility to serious injury [16].

Analyses of large-scale epidemiological databases further indicate that injuries sustained by children and adolescents not only occur with greater frequency relative to adult cohorts but are also associated with increased clinical complexity. Pediatric patients more often require prolonged hospitalization, advanced diagnostic imaging, multidisciplinary specialist consultations, operative management, including fracture fixation or neurosurgical intervention, and structured post-acute rehabilitation programs aimed at restoring functional capacity and preventing long-term disability [17]. The psychosocial consequences of such injuries, encompassing school absenteeism, emotional distress, and potential neurocognitive sequelae, additionally underscore the broader public health implications.

Available research also highlights the need to introduce and enforce legal regulations restricting children's access to e-scooters, including establishing a minimum age for users and requiring the use of appropriate protective equipment. It is also recommended to implement educational programs for parents, guardians, and children, covering safe riding practices, proper helmet use, and recognizing situations with increased risk of accidents. A comprehensive approach combining legal regulations with education and prevention is crucial to reducing the number of injuries in this particularly vulnerable group of users [18].

7. Injuries to bystanders

Although most of the literature on e-scooter injuries focuses on e-scooter users, there is evidence that bystanders, especially pedestrians and other road users, can also be victims of e-scooter incidents. Clinical reports and epidemiological observations indicate that scooter users' reactions to or collisions with pedestrians can lead to significant injuries, especially in urban environments with heavy pedestrian traffic and a lack of clear separation zones between

scooters and pedestrians. In one reported case, a pedestrian suffered a severe spinal injury after colliding with an e-scooter and required hospitalization and surgical intervention [19]. A review of the available scientific literature indicates that although a relatively small percentage of e-scooter injuries involve direct collisions with pedestrians, the consequences can be serious, particularly for older adults, children, and those with sensory impairments or limited mobility. A study analyzing data from the Injury Registry found that in crashes involving scooters and e-bikes, vehicle occupants and pedestrians comprised a significant portion of hospitalized patients, including children and older adults, highlighting the importance of including this group in road safety analyses [20]. Beyond direct collision injuries, the risk to pedestrians is increased by the presence of abandoned or left-behind scooters in pedestrian areas, which can lead to trips, falls, and lower limb injuries. Furthermore, experimental studies and those investigating participant reports indicate that pedestrians' subjective sense of safety significantly decreases in the presence of fast-moving scooters on sidewalks, which translates into an increased number of near-collisions and negative experiences for walking public space users [21]. Considering bystander injuries in scooter safety research is crucial from a public health and urban planning perspective. This highlights the need to consider appropriate regulations regarding permitted scooter riding locations (for example prohibiting riding on sidewalks), as well as designing infrastructure with a clear separation between pedestrian and micromobility spaces.

8. Prevention strategies.

Preventing injuries related to e-scooter use requires a multifaceted approach, encompassing both individual interventions and systemic solutions at the infrastructure and regulatory levels. The single most important protective factor remains the use of protective helmets. Observational studies indicate that the percentage of e-scooter users wearing helmets is extremely low, often not exceeding a few percent, even though head and facial injuries are among the most common and clinically burdensome consequences of accidents. Lack of head protection is associated with a significantly higher risk of concussion, intracranial hematomas, and facial fractures, which often require hospitalization and specialist treatment. The authors of the clinical studies emphasize that introducing mandatory helmet use could significantly reduce the incidence of severe neurological injuries and reduce the need for surgical interventions and intensive care [1,4]. Legal regulations and infrastructure solutions play an equally important role in injury prevention. Epidemiological analyses assessing the effects of the introduction of

shared scooter systems have shown a significant increase in emergency room visits, particularly at night and on weekends. This phenomenon correlates with increased alcohol consumption, limited visibility, and reduced traffic enforcement. The authors indicate that nighttime incidents are characterized by higher injury severity and more frequent hospitalization. The results of these studies suggest the potential effectiveness of interventions such as maximum speed limits, nighttime driving bans, sobriety checkpoints, and strict enforcement of scooter use regulations. Additionally, they emphasize the role of geofencing technology, which allows for automatic speed limits or restrictions on riding in specific zones and times, as a tool that can significantly reduce the risk of injury [22,23]. Increasing attention is also being paid to the influence of scooter design and riding position on the nature and severity of injuries. Clinical and biomechanical analyses indicate that small wheels, high maximum speed, and an upright user position contribute to a loss of stability, especially on uneven surfaces or during sudden braking. This configuration increases the risk of a violent fall, with the energy of the impact transferred to the head, upper limbs, and facial skeleton. The study authors note that scooter design can have a significant impact not only on the frequency of accidents but also on their clinical consequences, including the risk of pedestrian injuries. It is suggested that technical modifications, including improved vehicle stability, increased wheel diameter, optimized braking systems, and improved riding position ergonomics, may be a significant complement to preventive strategies and contribute to reducing the burden on the healthcare system resulting from e-scooter-related injuries [8,19].

9. Discussion

The literature review clearly indicates that e-scooter-related injuries are a growing and complex public health problem observed in many regions of the world. Despite differences in legal regulations, infrastructure, and scooter usage patterns, studies demonstrate consistent epidemiological patterns regarding the frequency of injuries, their mechanisms, and risk factors. The dominant mechanism of injury remains spontaneous falls, often related to loss of balance, uneven road surfaces, or sudden braking, while the most serious injuries are observed in collisions with other road users.

A particularly disturbing and consistently recurring finding is the extremely low rate of protective helmet use, despite the high incidence of head and facial injuries. Numerous studies confirm a significant association between the lack of head protection and an increased risk of

craniocerebral injuries, hospitalizations, and the need for surgical interventions. At the same time, drunk driving remains a significant risk factor, especially at night and on weekends, which is reflected in both the severity of injuries and the workload of emergency departments.

An important aspect of this problem is the pediatric population, which despite formal restrictions in some countries remains a group particularly vulnerable to injuries. Severe head injuries and fractures are more common in children and adolescents, and the use of protective equipment is also very low. Limited risk assessment and lack of road experience further increase this group's susceptibility to serious injuries, strengthening the argument for the introduction and enforcement of legal regulations and educational initiatives.

From a systemic perspective, e-scooter-related injuries generate a significant burden on healthcare systems, particularly emergency departments, trauma surgery, and neurosurgery. Analytical findings indicate that effective prevention requires coordinated action encompassing legal regulations, infrastructure solutions, technologies used by scooter operators, and vehicle design modifications. The lack of a comprehensive approach may lead to a further increase in injuries as micromobility becomes more popular.

10. Conclusions

Electric scooter-related injuries represent a rapidly growing and multifactorial public health challenge, closely linked to the dynamic expansion of urban micromobility. The available evidence consistently demonstrates a marked increase in emergency department visits and hospitalizations associated with e-scooter use across diverse geographical regions. The predominant injury mechanisms, particularly falls without the involvement of other road users, combined with identifiable behavioral risk factors such as alcohol consumption, excessive speed, nighttime riding, and low rates of helmet use, contribute to a characteristic injury profile dominated by craniofacial trauma and upper limb fractures. These injuries frequently require advanced diagnostic evaluation, specialist consultations, and, in a substantial proportion of cases, surgical intervention.

The burden imposed on healthcare systems extends beyond the acute management phase, encompassing prolonged hospitalization, rehabilitation, and the potential for long-term functional and neurological sequelae. Particular concern arises in relation to vulnerable populations, especially children and adolescents, who exhibit increased susceptibility to severe trauma due to developmental factors, limited road experience, and low adherence to protective

measures. Moreover, the risk of injury is not confined to scooter users; pedestrians and other bystanders may also sustain significant harm, underscoring the broader societal implications of unregulated micromobility expansion.

The findings of this review indicate that isolated preventive measures are insufficient to address the complexity of the problem. Effective risk reduction requires a comprehensive and coordinated strategy integrating legislative regulation, consistent enforcement of existing laws, infrastructure adaptation with clear separation of micromobility and pedestrian zones, and technological solutions such as speed limitation systems and geofencing. Mandatory helmet policies, restrictions on riding under the influence of alcohol, clearly defined minimum age requirements, and educational initiatives targeting both users and caregivers are essential components of such a framework. Additionally, optimization of vehicle design to enhance stability and braking efficiency may further mitigate injury risk.

In the context of the continuing expansion of micromobility systems, failure to implement evidence-based preventive strategies may result in a sustained increase in trauma incidence and healthcare system burden. A multidisciplinary approach involving public health authorities, policymakers, urban planners, healthcare professionals, and micromobility operators is therefore imperative to ensure that the benefits of electric scooters are not outweighed by preventable morbidity and societal costs.

Disclosures:

Author's contribution:

Conceptualization: Julia Modelska

Methodology: Julia Modelska, Anita Jeleń, Anna Podolska, Karolina Paluchowicz, Katarzyna Siwicka, Konrad Szewczyk, Laura Janasik, Patrycja Kociucka, Krzysztof Sadowski

Formal analysis: Julia Modelska, Karolina Paluchowicz

Investigation: Anita Jeleń, Anna Podolska

Resources: Karolina Paluchowicz, Katarzyna Siwicka

Writing-rough preparation: Julia Modelska, Katarzyna Siwicka

Writing-review and editing: Patrycja Kociucka, Konrad Szewczyk

Visualization: Laura Janasik, Konrad Szewczyk

Supervision: Krzysztof Sadowski, Laura Janasik

Project administration: Julia Modelska, Krzysztof Sadowski

Funding: The study did not receive external funding.
Institutional Review Board Statement: Not applicable.
Informed Consent Statement: Not applicable.
Data Availability Statement: Not applicable.
Acknowledgements: Not applicable.
Conflicts of Interest: The authors declare no conflicts of interest.
All authors have read and agreed with the published version of the manuscript.

Declaration of generative AI and AI-assisted technologies in the writing process: In preparing this work, the authors used ChatGPT (OpenAI) for the purpose of language editing and grammar correction only. After using this tool, the authors reviewed and edited the text as needed and accept full responsibility for the substantive content of the publication

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